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SOUNDING ROCKET FOR MEASURING RADIATION IN IONOSPHERE

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In France, A New Tool for Ionospheric Studies:

THE SCATTER PROBE

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ABSTRACT

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The National Center for Telecommunications Studies has just started to use an important instrument for the study of the high atmosphere. Functioning on a new principle, namely, the incoherent scattering of radio waves by the ionospheric plasma, the new apparatus permits to make uninterrupted measurements of certain phenomena occurring in the ionosphere, which is something no other experimental technique has been capable of doing. /9*

It may seem paradoxical at a time when it is possible to send rocket probes to study "on site" phenomena occurring in the Earth environment, to revert to ground installations for the same purpose. Actually, space research as a means of knowing the Earth environment must use ground equipment as well as instruments carried by rockets or satellites. The simultaneous use of both techniques permits to check the results of one method against those of the other. This is also the opinion of the National Center for Space Studies, ~~who~~ which has taken over the financing of the operation. Author

*Numbers given in margin indicate pagination in original foreign text.

Above approximately 60 kilometers altitude the atmosphere is dense enough for the molecules which compose it to be permanently ionized by solar radiation. The flux of solar energy and in particular the daytime ultraviolet radiation comes in contact with neutral particles of the atmosphere and causes the formation of ionized particles whereby each molecule is decomposed into a positive ion and the negative electron.

If the medium is of low density so that collisions between particles are not too frequent the recombining of the positive and negative elements is unimportant and the atmosphere remains ionized. Actually, the number of ionizable particles decreases with the altitude, the probability for their remaining ionized without recombining increases with the altitude and there occurs a compromise between these two phenomena. The result of it is that the degree of ionization is at its highest point around 300 kilometers altitude.

The medium then behaves like a plasma. The forces which organize this plasma are either the pressure or the Earth's magnetic field by means of its action on the electrically charged particles. In lower altitudes the pressure is still noticeable and the ionized medium can be considered, as a first approximation, to be composed of layers which are concentric with the Earth under the influence of gravity. These layers are called the ionosphere. But above approximately 500 kilometers the magnetic forces become more important and the spherical structure of the medium is no longer preponderant. This is the magnetosphere.

Probes and Satellites

Before the beginning of the space age the essential instrument for ionospheric studies was the vertical probe. Its principle is simple. In the same way that a mirror reflects light rays but lets X rays go through, an electrically charged medium behaves, with respect to an electro-magnetic wave, either as a reflecting conductor or as a transparent insulator depending on the wave length. Thus there exists for each altitude a critical wave length which is a function of the degree of ionization in that particular altitude. The medium is transparent to the wave lengths which are smaller than the critical wave length; wave lengths which are larger are reflected by it.

It is therefore possible to trace the profile of the ionization as a function of the altitude by directing toward the ionosphere--as with a radar--radio signals whose frequency can be varied and by studying the signals reflected back to the ground. The apparatus used for this is a "variable frequency ionospheric probe." This is of course only possible in the medium below the maximum ionization and the upper part of the ionosphere cannot be studied with this technique.

In the meantime the existence of satellites has permitted to study the upper ionosphere on site.

However, in order to know a geophysical phenomenon of global scale, it is useful to study its characteristics in space as well as in time. A satellite is perfectly suitable for the studies in space, since it covers a great distance in a short time, but it does not permit to study the variations in time of a given spot. Ground instruments are therefore indispensable to geophysical research.

What was still needed, however, was a technique capable of reaching the upper ionosphere. "Incoherent scattering" has been found to be such a technique.

"Incoherent" Scattering

The scatter phenomenon is well known. We know, for example, that the blue of the sky is a phenomenon of sunlight scattering by the electrons bound to the atoms of the atmosphere. In the case of free electrons of the ionospheric plasma the process is somewhat different.

Under the influence of an electromagnetic field a charged particle takes up an oscillatory motion and, radiating energy, behaves like a scatterer. In a gas, which is composed of a great number of particles each of which is a scatterer, each scatterer causes a phase shift due to its relative position.

If the medium is homogeneous the phase distribution is uniform and the total scattered energy is zero. Scattering can only exist if there are inhomogeneities in the ionization density. As a matter of fact, such inhomogeneities are naturally existing: they are fluctuations of thermal origin which are linked to the gas temperature. The incoherent character of these fluctuations gives its name to this type of scattering.

But the ionospheric plasma is composed of different particles: electrons and ions. This complicates the phenomenon. The electrons are lighter and therefore easier to move and therefore furnish the essential part of the scattered power. The motion of the electrons is, however, affected by the presence of ions. The latter move relatively slowly with respect to the electrons and therefore create electric fields around the electrons called "space charges". The ions thus tend to govern the motion of the electrons and the distribution of the latter matches the fluctuations of the ion density.

The scattered power is therefore that of an electron gas whose density fluctuations are those of an ion gas. More precisely:

. The total amount of scattered power is proportional to the number of electrically charged particles, i.e. to the ionization;

. The electron velocity--which is a function of the electron temperature--and the ion velocity--which is a function of the temperature and mass of the ions--interfere with each other to give to the particles which play the role of scatterers velocities which create a Doppler effect, i.e. a frequency change of the scattered electromagnetic wave. Since the particle velocities are distributed within a certain range, the scattered signal is spread over a certain frequency band and its spectrum can be defined (distribution of power as a function of frequency).

Data are therefore to be found in the scattered signal: its level depends on the electron density, its frequency spectrum depends simultaneously on the electron temperature and on the mass of ions composing the medium.

The practical problem of the analysis consists in reducing these data from the experimental result. It is necessary to find the most probable values for the unknown parameters which are contained in the known information.

The use of the incoherent scattering phenomenon requires therefore considerable technical means. In spite of this, three American installations and one French installation[1] have been built since 1958 when the main ideas on the phenomenon were published by Professor Gorder of Cornell University (New York).

All the foreign equipment works on the principle of the pulsed radar. A high power transmitter radiates vertically a pulse of given duration by means

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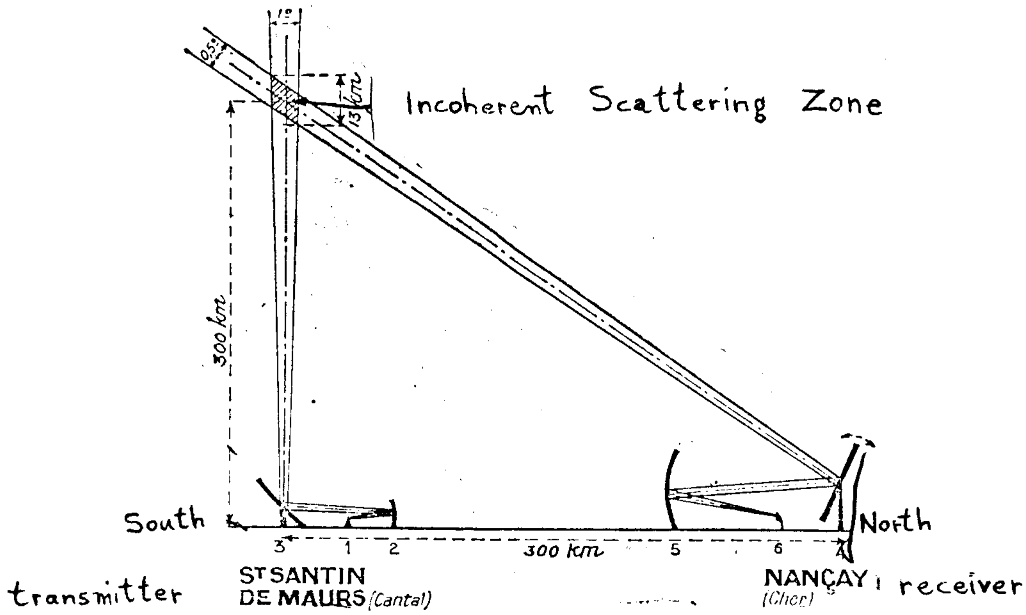
[1]Only the most important installations which are already in operation are mentioned here. The Royal Radar Establishment at Malvern (United Kingdom) has an almost completed installation.



The transmitting antenna is made up of a horn (1) located on ground. This horn sends the signal to a first parabolic reflector (2), which sends it in turn to the main reflector (3). The latter reflector, whose projection on the horizontal plane covers an area of 20 meters by 100 meters, radiates vertically, in a beam of 1 degree of aperture. The receiving antenna receives the energy first on a plane mirror (4) made up of ten orientable panels of 20 meters by 40 meters dimension. This mirror reflects the radiated energy toward a second mirror (5) (the latter is a sperical mirror) which concentrates this energy at its focus. The receiving antenna (6) proper is located in this focus. The aperture of the beam is 1/2 degree. The volume studied is defined by the intersection of the two beams of the two antennas. The altitude of the volume under study can be varied by rotating the Nançay plane mirror. At 300 kilometer altitude the height of the volume where the incoherent scattering of the transmitted waves can be studied is 13 kilometers.

of a large antenna. The scattered wave is picked up by the same antenna and directed to a low noise receiver. Each time of reception corresponds to an altitude from which the scattered signal comes (one millisecond corresponds to a round trip of 300 kilometers at the speed of light, i.e. to an altitude of 150 kilometers). The thickness of the altitude layer under study is determined by the duration of the pulse in question (a pulse of 0.1 millisecond takes up a length of 15 kilometers in space).

Between the Massif Central Mountains and the Sologne Region

The probe of the National Center for Telecommunications began to function on 30 September 1965.[1]

Although the phenomenon under study is the same, the principle on which the equipment is based is different. The equipment was essentially designed to measure the spectrum of the scattered signal. In order to do this, two different antennas are used instead of one, one for the transmission and one for the reception. This permits the use of a continuous wave instead of pulses. The fixed transmission antenna radiates vertically the continuous wave. The movable receiving antenna beam intersects the beam of the fixed antenna at an altitude chosen by proper orientation of the antenna. The volume studied is therefore defined by the geometry of the antennas. The scattered power is received by the movable antenna and directed to a low noise receiver. It is possible, since the transmission functions continuously, to extend the duration of the measurement all the time needed for a spectral analysis of the scattered signal.

[1]The project has been carried out under the responsibility of François du Castel, and his collaborators Henri Carry, Michel Petit, Michel Reyssat and Philippe Waldteufel.

This technique permits a much better measurement of the parameters of the atmosphere which affect the scattering spectrum, than the radar pulse technique. It also permits a better definition of the altitude to which the studied volume extends. On the other hand, it is not possible to obtain an ionization profile as rapidly as with the pulse method, since the orientation of the receiving antenna must be changed each time the measurement altitude has to be changed.

The use of this technique in France was only possible because of the existence of the big radiotelescope built in Nançay (Cher) by the Paris-Meudon Observatory.

The receiving station of the probe is located there and uses the orientable plane mirror of the radiotelescope which measures 200 meters by 40 meters. Since the mirror is movable in an East-West direction the transmission station was installed 300 kilometers South of it, thus permitting a better definition in height in the altitude zone between 300 and 500 kilometers. The station was located on a plateau in the Massif Central Mountains at Saint-Satin-deMaurs (Cantal) and a fixed antenna of effective dimensions was erected (100 meters by 20 meters).

For the transmission the most powerful tube presently in existence was selected for the frequency range under study (935 MHz). At the receiving end, the information output is accomplished with modern numerical coding techniques which can be used directly by a computer.[1]

[1]The French company Thomson-Houston (for the transmitter), the French Enterprise Company and the Research Center of the Compagnie Genérale d'Electricité (for the antennas) and the National Geographic Institute (for the accurate positioning) have all been associated with this program. The receiver was built by C.N.E.T. which has studied and directed the program as a whole.

From First Results to Perspectives

The first results obtained by the scatter probes have given weight to a drive to understand better the ionospheric plasma which surrounds the Earth and the laws which govern this plasma. These results have permitted to verify the presence of helium between the region where oxigen is predominant at the lower altitudes and the region where hydrogen is predominant at the very high altitudes. Moreover these results have permitted to make a study of the thermodynamic lack of equilibrium between the ion temperature and the electron temperature in the high atmosphere.

It is therefore a valuable tool which serves the needs of basic research. The specialized research laboratories[1] want to embark upon such a program. The funds which are necessary for it should hopefully be forthcoming. Much work can be done by the French researchers using this probe to its fullest extent. It is hoped that the other European researchers will be able to benefit from this probe and to be part of the scientific community in charge of its development.

[1]The funds from the National Center for Space Studies amounted to 5,500,000 Francs.